

Wireless Networked Radios: Comparison of Military, Commercial, and R&D Protocols

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ABSTRACT

The U.S. Military is in the process of specifying and developing a new wireless networking radio capable of transmitting secure/nonsecure voice, video, and data between its mobile vehicles, aircrafts, and ships. This paper examines some of the existing wireless radio systems and compares their features to those characteristics desired. Included in the discussion are the NTDR, VRC-99, IEEE 802.11, ICAO VHF Data Link Mode 3, NRL MCA, WINGS, and MANet. It is found that while these developments are significant, additional research and development is required to meet the DoD's new wireless network radio operational requirement.

1.0 INTRODUCTION

The Department of Defense has initiated the development of its next generation of radios in order to increase the capabilities of its forces and reduce the overall lifetime costs associated with its radios. These radios will be software (re)programmable, modular in both hardware and software design, and capable of being reconfigured to operate with different waveforms and protocols anywhere in the 2 - 2000 MHz band. While the next generation of radios must provide backward compatibility with legacy radios, cryptographic devices, and Military Standards (e.g. SINCGARS, MIL-STD-188-181/2/3, HaveQuick, etc.), they must also provide for new capabilities to ensure the readiness of the U.S. Military into the 21st Century.

The U.S. Navy's Digital Modular Radio (DMR) [DMR] is the first radio to be developed to meet these operational requirements as they apply to Navy ships, submarines and shore installations. Lessons learned from DMR and other DoD radio programs will be applied to the DoD's Joint Tactical Radio System (JTRS) [JTRS]. All services will migrate to the family of radios developed under the JTRS Joint Program Office by the FY02/03 timeframe.

One of the primary new capabilities to be implemented in DMR and JTRS is a line-of-sight (LOS) wireless networking radio capable of transmitting voice, video and data to/from any mobile node (ship, HMMWV,

tank, helicopter, aircraft, etc.) in the wireless network. The new wireless networking capability will offer; (a) automatic network formation and maintenance, (b) automatic relaying to extend LOS range, (c) independent encryption and QOS guarantees to each user service (voice, video, data), (d) robustness to jamming, denial of service, and spoofing attempts, and (e) robustness to random node failures (either due to adverse propagation conditions or to radio failures). This new capability will allow U.S. Forces to deploy more rapidly and perform their missions while on the move.

Many protocols and waveforms have been developed to support communications between mobile nodes. Fig. 1 groups many of these developments into three broad categories; DoD based, R&D based, and Commercial based. Ideally, the DoD could use an existing standard, commercial or otherwise, to full-fill its wireless networking operational requirements. This paper will examine a few examples from each of these categories with respect to the Military missions and operational environment. It will then describe some of the issues in mapping wireless network radio protocols and waveforms into the technical architecture of next generation radios.

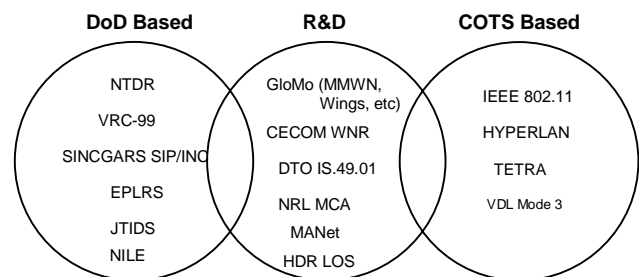


Fig. 1: Some wireless networking radios, protocols, and waveforms existing today.

2.0 DoD EXAMPLES

2.1 Near Term Digital Radio (NTDR)

The NTDR is an Army tactical radio developed for mobile networked IP data only applications by ITT (Ft. Wayne, ID). It is intended for use as a backbone radio for Tactical Operations Center (TOC) to TOC communications between echelons Brigade and below.

The radios are designed to self-organize, as shown in Fig. 2, into a dynamic two-tiered network scheme of backbone cluster heads and affiliated cluster members [Zavgren]. Data is routed and relayed automatically between users on three separate frequency hopping patterns. Data can hop across up to seven nodes. Cluster members are automatically handed off between backbone cluster heads while roaming. The NTDR clustering architecture is self-healing in the event of a cluster head failure. The radio uses ROSPF (Radio Open Shortest Path First) as its routing protocol. ROSPF eliminates the HELLO protocol used by OSPF to reduce network overhead bandwidth. Topology data is derived from radio node tables stored in each NTDR.

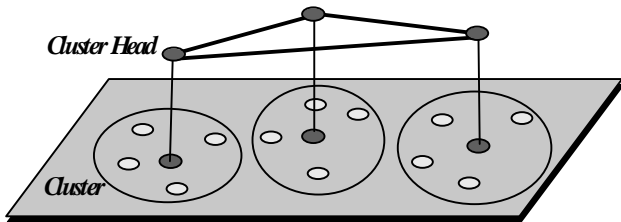


Fig. 2: Two-tiered networking structure of NTDR [Zavgren].

NTDR uses CSMA/CD (Carrier Sense Multiple Access/ Collision Detection) as its RF media access control (MAC) protocol for data transmission. The sequence of events that occur during transmission of a data packet is shown in Fig. 3. The source radio listens for a clear channel before sending a Request To Send (RTS) burst to the destination radio. The RTS burst is always sent by the source radio and serves the purpose of requesting access to the channel. The destination radio returns a Clear To Send (CTS) burst back to the source radio to indicate the channel is free and that it is available to accept a data packet. On reception of the CTS burst from the destination radio, the source radio transmits the variable length data packet. The destination radio demodulates and decodes the received data packet through the CRC error detection process. If the CRC is OK, then the destination radio transmits the Link ACK burst to the source radio to indicate successful reception of the data packet.

Source NTDR

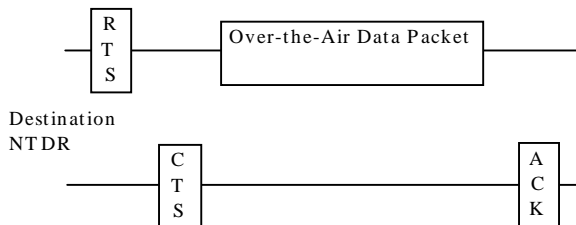


Fig. 3: NTDR MAC Protocol.

The NTDR transmits data packet information at a burst rate of 375 kbps at up to 20 Watts (+43 dBm) in the 225- 450 MHz band [Modem]. The information bits are first coded by a $\frac{3}{4}$ rate, $k=7$ constraint, convolutional encoder. The resulting coded signal is modulated onto a Direct Sequence Spread Spectrum (DSSS) QPSK waveform at 500 kbps. A 4 MHz Transmission Security (TRANSEC) pseudo random sequence is used for spreading the coded bits. This results in 16 chips of DSSS modulation per QPSK symbol. NTDR also incorporates the Krypton embedded Communication Security (COMSEC) NSA type 1 device.

While the performance of the NTDRs depends on many variables, for a simple point-to-point connection the maximum throughput is about 250 kbps and the round trip IP packet delay is about 140 msec for large IP packet sizes [Bryan]. It is clear that the MAC protocols must be efficient and processed by the radio quickly to maintain high data throughputs.

2.2 AN/VRC-99

The AN/VRC-99 is a direct sequence spread spectrum, half-duplex radio that operates in the L-band. It is designed and manufactured by GEC-Marconi Hazeltine (Greenlawn, NY). It is a data/voice networked radio, allowing up to 16 users by using a 27 slot TDMA (23 3.7 msec slots for data and 4 4.6 msec slots dedicated to voice) MAC protocol. Each of the 23 data slots can be allocated to an individual radio node and multiple slots can be assigned to any individual radio node. Data slot assignments are presently allocated statically vice being allocated dynamically. The AN/VRC-99 supports IP data from a standard Ethernet LAN and up to four simultaneous voice nets.

During each slot, the burst transmit data rate can be varied between those values shown in Table 1 by adjusting the spreading gain. The 20 Mcps chip rate, and thus the transmit bandwidth, remain the same for all data rates. The 3 dB BW is approximately 16 MHz. Notice that there is an optimum IP packet size that maximizes the throughput for each of the burst data rates. Each node in the network is aware of the slot schedule and maintains a connectivity list for all radios in the network. This information is used by each radio to perform automatic routing of data and voice messages through the wireless network [THAAD].

The AN/VRC-99 includes embedded TRANSEC and COMSEC. The TRANSEC algorithms include both Direct Sequence Spread Spectrum and Frequency Hopping. The Frequency Hopping can be disabled by the user (say to reduce co-site interference problems).

Table 1: Burst Transmit Data Rates for AN/VRC-99.

Data Rate (Mbps)	Spread Factor	IP Packet Size for Max Throughput	Max Thruput Per Slot	Chip Rate (Mcps)
10	2	2546 Bytes	195.9 kbps	20
5	4	1202 Bytes	92.5 kbps	20
2.5	8	530 Bytes	40.8 kbps	20
1.25	16	194 Bytes	14.9 kbps	20
0.625	32	110 Bytes	8.5 kbps	20

3.0 COMMERCIAL EXAMPLES

3.1 IEEE 802.11 Wireless LAN

The IEEE 802.11 Wireless LAN standard defines the protocol and waveform of data communication equipment for wireless connectivity for fixed, portable, and moving nodes within a local area. The standard includes a single MAC sublayer protocol and three physical (PHY) layer waveforms. Fig. 4 shows the close interaction of the IEEE 802.11 standard with the other IEEE 802 standards.

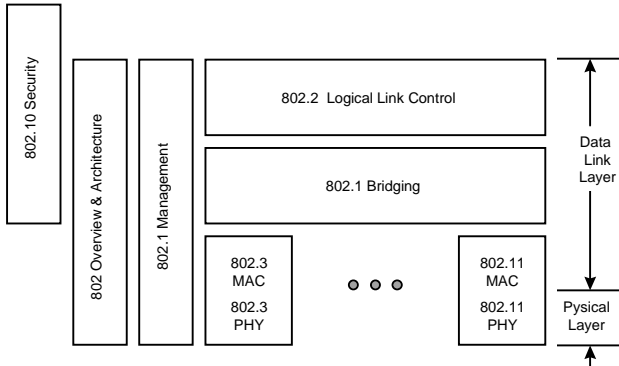


Fig. 4: Interaction of the IEEE 802 standards with 802.11.

The IEEE 802.11 MAC standard provides asynchronous, connectionless service [Day]. A connection-oriented service is being considered for later phases of this standard. The MAC supports operation working either through an Access Point connecting the wireless LAN to a wired LAN or peer-to-peer (no relaying). In addition, the MAC supports power management features, authentication, and (re)association.

The IEEE 802.11 MAC frame format is variable in length and supports control, data, and management transmissions [802.11]. The complete MAC frame is designated as the MAC Protocol Data Unit (MPDU). The control MPDUs vary in size between 14-20 bytes (112 - 160 bits), the data MPDUs vary in size between 34 - 2346 bytes (272 - 18,768 bits), and the management MPDUs vary in size between 30 - 2340 bytes (240 - 18,720 bits).

The IEEE 802.11 standard supports three PHY standards which all work with the same MAC standard.

These are the Frequency Hopping Spread Spectrum (FHSS), the Direct Sequence Spread Spectrum (DSSS), and the Infrared (IR) standards. Each PHY standard has a 1 Mbps and a 2 Mbps burst rate mode of operation. The PHY standard is further divided into two sublayers; the Physical Layer Convergence Procedure (PLCP) sublayer simplifies the interface to the MAC, and the Physical Medium Dependent (PMD) sublayer provides for transmission, reception, and a channel assessment. Both the FHSS and the DSSS are specified to operate in the 2.4 GHz ISM band. The DSSS has a chip spreading factor of 11 and uses DBPSK (1 Mbps mode) or DQPSK (2 Mbps mode). The FHSS uses an orthogonal hopping pattern, M=2 GFSK (1 Mbps mode) and M=4 GFSK (2 Mbps mode). The preamble and header are always transmitted at 1 Mbps.

3.2 VHF Data Link (VDL) Mode 3

The International Civil Aviation Organization (ICAO) is planning to modernize its air traffic control communication infrastructure within the next 10 years with the adoption of the ICAO VHF Digital Link (VDL) TDMA Mode (VDL Mode 3) Standard and Recommended Practices (SARPS) [FAA]. The system will be phased in to replace the existing analog voice (double-sideband AM) based systems and will operating in the same 112.000 – 136.975 MHz frequency band in 25 KHz channels.

VDL Mode 3 uses a differentially encoded 8-PSK modulation with a rate $\frac{1}{2}$ Golay code for forward error correction. The symbol rate is 21 kbps (31.5 kbps). Each TDMA frame is 120 msec in duration and is either configured as four 30 msec slots or as three 40 msec slots. The guard interval is adjusted to provide the 4-slot configuration up to 200.6 nmi range and the 3-slot configuration up to 609.4 nmi range. Each slot is further divided into two subslots, the first for control and management (M) and the second for voice or data transmissions (V/D). Fig. 5 illustrates the various 4-slot configurations and includes (all within one 25 KHz frequency channel) [VDL]:

- (1) 4V – provides 4 user nets a half-duplex voice channel,
- (2) 2V2D – provides 2 user nets both half-duplex voice and data channels,
- (3) 3V1D – provides 3 user nets a half-duplex voice channel and one shared data channel,
- (4) 3T – provides a trunked capability shared by all users for data or voice using $\frac{3}{4}$ slots per frame.

A maximum of 60 nodes can be in a single user net. The arrow indicates the control and management uplinks and downlinks.

Voice service is similar to the present push-to-talk DSB-AM with only a single speaker allowed to transmit at a time. Provisions are provided to guarantee voice transmissions in the event of an emergency. The frame length is designed such that the maximum user-to-user voice delay will be less than 250 msec. Data transmissions are requested from a central control stationed at the ground station through the M subslots. Data transmissions are scheduled as 576 bits per D slot and in up to 7 successive frames. Longer messages require multiple requests to send.

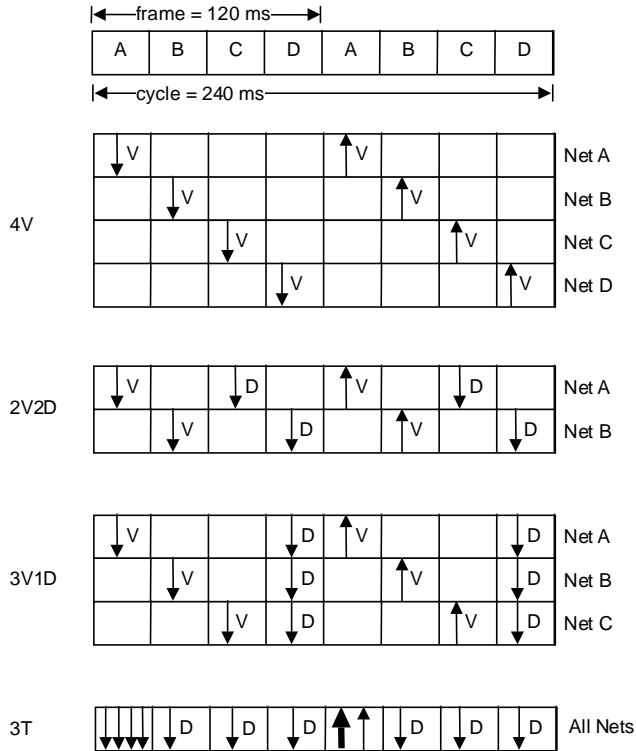


Fig. 5: 4-Slot Configuration Timing Diagrams [VDL].

4.0 R&D EXAMPLES

4.1 NRL Multichannel Architecture

The Naval Research Laboratory (NRL) Multi-Channel Architecture (MCA) defines a suite of protocols used to implement a fully-mobile, multi-hop IP subnet capable of supporting both voice and data traffic over RF channels as low as 2400 bps and as high as T1 or greater. It is suited to airborne backbone, ship-to-ship, and vehicle-to-vehicle networks. The subnet uses a combination of virtual-circuit and packet switching techniques. The subnet uses the broadcast nature of the RF link layer to implement efficient unicast and broadcast capabilities for both data and voice applications.

Distributed control algorithms allow the subnet to respond very quickly to connectivity changes.

The MAC layer defines a time-slotted frame that determines when a node is allowed to transmit special control information that is used to self-organize the subnet. At any given time the number of nodes that participate in the subnet reorganization protocol is limited to the number of slots per frame, which is set at subnet startup. Although the MCA can operate over a single RF channel, virtual-circuit performance is usually improved significantly when several RF channels are available. The MCA protocols were demonstrated in 1996 over a multihop HF radio network as part of NRL Data / Voice Integration Advanced Technology Demonstration [NRL].

4.2 DARPA's Global Mobile Information Systems

Since 1994, DARPA Information Technology Office has been sponsoring a number of programs investigating Global Mobile Information Systems [GloMo]. The goal of these "GloMo" programs is to develop the enabling technologies to provide the military with a tactical wireless environment that; (1) is capable of rapid deployment where there is no preexisting infrastructure, (2) provides enhanced global connectivity to the warfighter, (3) supports communications during all categories of mobility, (4) provides secure and survivable access to multimedia information services and (5) adapts to changing end-user environments.

Of the many GloMo programs, the UCSC/Rooftop Communication Wireless Internet Gateway (WINGS) has demonstrated encouraging over-the-air data communication performance. The WINGS-I protocol architecture is shown in Fig. 6 and includes Wireless Internet Routing Protocol (WIRP), UDP transport layer, IP network layer, and the FAMA-NCS MAC layer protocols [Garcia]. FAMA-NCS is similar to the CSMA/CA MAC layer defined in IEEE 802.11 except that it provides special features to help minimize collisions caused by possible overlapping transmissions (hidden node problem). RIP and RIPv2 have also been implemented in WING I to extend inter-network routing to the wireless environment seamlessly. Plans are to add TCP, multi-channel capabilities, IP multi-hop multicast routing protocols, security features, and other refinements into a WING-II prototype.

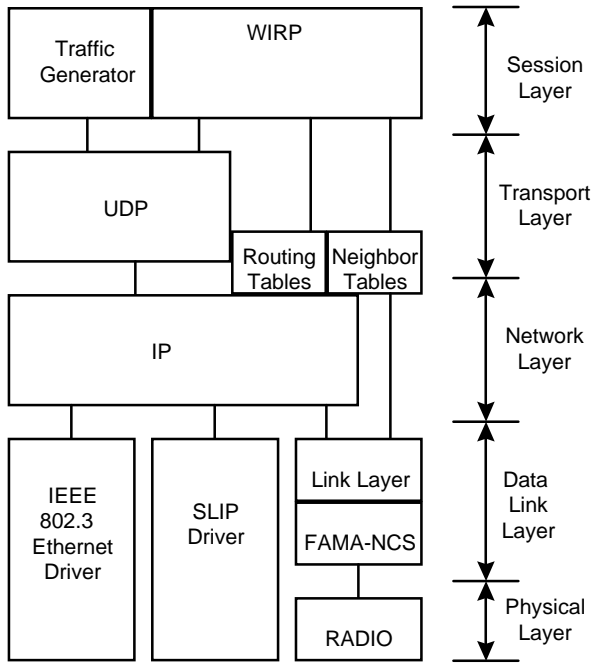


Fig. 6: WINGS I Protocol Architecture [Garcia].

4.3 Mobile Ad Hoc Networking (MANet)

The Internet Engineering Task Force (IETF) MANet Working group is developing a Mobile Ad Hoc Network routing specification to be proposed as a Internet Standard [MANet]. Presently, the working group is evaluating different approaches based on software and hardware prototypes and is anticipating to submit a protocol specification to the Internet Engineering Steering Group (IESG) by Dec. 1999. The proposed MANet specifications include protocols for (1) automatic network formation, (2) route discovery and maintenance, (3) reliable multicast and unicast, (4) some quality of service “best efforts”, and (5) multi-hop relaying. The protocols are being designed for hundreds of mobile nodes with limited connectivity bandwidths.

5.0 DISCUSSION & IMPLEMENTATION ISSUES

Sections 2, 3, and 4 have briefly described examples of wireless network radios, protocols, and waveforms which exist today. While these developments are substantial, none provide a complete solution for the Military’s desired wireless networking capability to be implemented in the JTRS. Table 2 compares some of the desired features with those systems described in this paper.

The JTRS wireless networking capability must be self-organizing so that troops can concentrate on their

mission. The network and the radio must support multi-hop relaying within an “ad-hoc” wireless network of up to one hundred nodes to extend the LOS range. Some U.S. Army applications envision several hundred mobile nodes. Latency increases are anticipated for each successive hop as well as hop limit restrictions for some services.

Table 2: Comparison of features provided by some of today’s wireless network radios with those desired for JTRS.

	Self-Organize Net	Multi-Hop Relay	Supports 100 Nodes	QOS Guarantee	Voice	Video, sync. Serial I/O	IP Data	BW on Demand	INFOSEC, Authentication	Robust Waveform	Adequate Range
NTDR	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y
VRC99	Y	Y	N	Y	Y	N	Y	N	Y	Y	Y
802.11	Y	N	Y	N	N	N	Y	Y	N	N	N
VDL-3	Y	N	N	Y	Y	N	Y	N	N	Y	Y
MCA	Y	Y	N	Y	Y	N	Y	Y	-	-	-
WINGS	Y	Y	Y	N	N	N	Y	Y	-	-	-
MANet	Y	Y	Y	N	N	N	Y	Y	-	-	-

The wireless network must support voice, video (including synchronous serial I/O), and IP data integrated services. The voice service must support multiple voice “nets” to allow for communication between tens of users. Complicating the support for integrated services is that the Military requires guaranteed bandwidth for certain services. For instance, both the USMC and the USN require at least three separate IP LANs based on different security classifications (unclassified, classified, and top-secret). While in-line encryption devices can “merge” the traffic into a single IP LAN, each IP LAN must be guaranteed a minimum bandwidth when required. However, when not in use, the bandwidth should be reallocated to other services in need of bandwidth. A similar situation arises with supporting multiple voice “nets” where each can potentially be running at a different level of encryption.

Fig. 7 highlights the implementation of wireless network radio functions in the DMR and JTRS technical architectures based on the PMCS guidelines (with the exception that the red-bus in the PMCS guidelines has been hidden in the RED I/O functional block) [PMCS]. The real-time functions of the Physical waveform and MAC protocols must be implemented close to the ADC/DAC section of the radio and should probably not rely on data transfers across the black bus due to its increased latency. Upper Link layer protocols and intra-networking layer protocols which are less latency critical can be off-loaded to other general processing modules in the black side of the radio. The goal is to allow for a “relay radio” design that does not require embedded

COMSEC for application to unmanned operations say as a hill top relay or within a UAV.

One of the major unresolved issues is where should the radio stop and external baseband devices take over. It is sometimes stated that inter-networking functions belong outside of the radio and that intra-networking functions belong inside the radio. Recall that inter-networking provides mechanisms for running applications across heterogeneous networks and requires transport and network protocols [HDRLOS]. Inter-networking provides the mechanism by which user services are supported. Both NTDR and WINGS support many inter-networking features much to the approval of its users.

Fig. 7 illustrates the difficulties when a single radio must support multiple black and red user services. The control and management of these services, their cryptographic keys, etc. becomes complicated from both the radio designers and the radio users perspective. As described above, the wireless network radios today assume a single user for each wireless radio node with only one or two services for that single user.

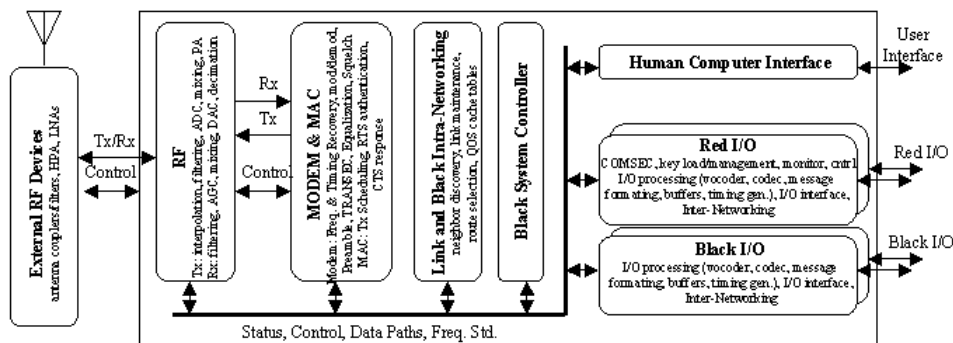


Fig. 7: Wireless Network Radio Technical Architecture.

6.0 CONCLUSIONS

The JTRS Joint Program Office is planning to develop a wireless networking capability for the U.S. Military by FY02 timeframe. This paper has briefly examined several wireless networking radios, protocols, and waveforms which exist today and which might be applicable to this effort. It was shown that while each system has its merits, none meets the U.S. Military's desired wireless networking characteristics. It appears that key developments in MAC and other protocols are required to support multiple independent voice, video, and data services in a wireless "ad hoc" network. These protocols must be matched to a physical layer waveform which is robust to multipath propagation, interference, and

jamming. It was also shown that the implementation of a network radio supporting multiple independent secure/nonsecure user services appears to require further investigation.

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